

## **A Perception-based Study of Sonorant Assimilation in Korean\***

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### **1. Introduction**

Speech perception phenomena have been drawn on by researchers in the area of phonological theory to elucidate synchronic phonological processes such as neutralization (Steriade 1995, 1997), consonant/consonant metathesis (Hume 1998, 2001), place assimilation (Jun 1995), etc. It has also been found that listeners' perceptual abilities are influenced by their native language experience (e.g. Hume et al. 1999).

In this paper, this bidirectional interplay between speech perception and phonology is investigated further. The influence of speech perception is examined as a possible means of understanding sonorant assimilation in Korean. Two types of sonorant assimilation are attested in Korean. First, when a nasal /n/ is adjacent to a lateral, the nasal is lateralized, as in /non + li/ → [nolli] 'logic', /səl + nal/ → [səllal] 'New Year's day'. Korean is not the only language with n-lateralization in n/l sequences. This process is attested in a wide range of languages such as Klamath, Ponapean, Toba Batak, Leti, Terafene dialect of Flemish, Rendille, Somali, and Udi. In different languages such as Tatar and Yakut, l-

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nasalization is observed in *n/l* sequences. Second, when a lateral is preceded by a noncoronal nasal /*m*/ or /*ŋ*/, the lateral is nasalized, as can be seen in /*sam* + *lyu*/ → [samnyu] 'third rate', /*yəŋ* + *li*/ → [yəŋni] 'profit'. L-nasalization in /*ml*/ is also found in Tatar and Yakut<sup>1</sup>. However, unlike n-lateralization in *n/l* sequences, l-nasalization in /*ml*/ and /*ŋl*/ sequences is a rather uncommon process cross-linguistically and to our knowledge, there is no language with nasal-lateralization in those sequences.

Four important questions can be raised concerning n-lateralization and l-nasalization. First, why is n-lateralization or l-nasalization in *n/l* sequences a cross-linguistically common process while l-nasalization in /*ml*/ and /*ŋl*/ is not? Second, with respect to the *n/l* sequences, why are both n-lateralization and l-nasalization attested in different languages? Third, why is l-nasalization rather than nasal-lateralization observed in the /*ml*/ and /*ŋl*/ sequences in Korean? In this paper, we propose that these questions can be answered by recourse to speech perception. Following Koher (1990), Hura et al. (1992) and Steriade (2001), we hypothesize that both n-lateralization and l-nasalization occur in *n/l* sequences since both are perceptually licensed changes. We hypothesize that the change of /*l*/ to [n] rather than the change of /*m*/ or /*ŋ*/ to [l] occurs in /*ml*/ and /*ŋl*/ sequences since the former is a perceptually less noticeable change. Another important question to be raised is why the change of /*n*/ to [l] is preferred to the change of /*l*/ to [n] in Korean, given that both n-lateralization and l-nasalization are perceptually allowed changes and thus both are attested in *n/l* sequences cross-linguistically? We propose that listeners' perceptual abilities are not the only factors shaping the phonological patterns of languages and that this question can be answered by taking into account articulation as well as perception.

The influence of phonology on speech perception is also explored in this paper by comparing Korean listeners' perceptual abilities with those of Moroccan Arabic and Swedish listeners, whose native languages show different phonological patterns in the nasal/liquid sequences from Korean. According to the P-map hypothesis (Steriade, 2001), listeners' perceptual abilities are the same regardless of the native language of a listener and sound patterns found in that language. This paper provides a test of this hypothesis through perception experiments involving Korean, Moroccan Arabic and Swedish listeners.

Our results suggest that l-nasalization, i.e. the change of /*ml*/ and /*ŋl*/ to [mn] and [ɲn], respectively, is driven by perceptual considerations. Our results from Korean listeners show that the change of /*l*/ to [n] is perceptually less noticeable than nasal-lateralization in the /*ml*/ and /*ŋl*/ sequences, as we expected. Our results show no significant difference in *n/l* sequences between the change of /*l*/ to [n] and that of /*n*/ to [l], suggesting that both n-lateralization and l-nasalization are perceptually allowed changes.

<sup>1</sup> Tatar: /*khanım* + *lAr*/ → [khanımnar] 'ladies' (Poppe 1963) (/Ä/ is the archiphoneme of [ä] and [a].)  
Yakut: /*olom* + *lAr*/ → [olomnor] 'fords' (Krueger 1962) (/A/ is the archiphoneme of [a], [e], [o], and [ø].)

This paper is organized as follows. In section 2, assimilation patterns in /n/, /ln/, /ml/ and /ŋ/ sequences found in Korean are given. In section 3, the realization of n/ sequences in other languages is presented. We discuss the possible motivation behind the patterns of assimilation in nasal/liquid sequences and posit a hypothesis based on that in section 4. In section 5, the realization of nasal/lateral sequences in Moroccan Arabic and Swedish is given. In section 6, an outline of the perception experiment, which is designed to test the hypothesis posited in section 4, is given, and the results of the perception experiment and discussion are given in section 7. The results and discussion of the linear regression analysis, which was done to investigate which language-universal and language-specific cues are involved in speech perception and how much their influence is, are given in section 8. In section 9, we provide an account of sonorant assimilation patterns in Korean based on our perception experiment results.

## 2. Sonorant Assimilation in Korean

In Korean, two types of assimilation processes are attested when a lateral is adjacent to a nasal. First of all, when a nasal /n/ is followed by a lateral, the nasal is lateralized, as the examples in (1) illustrate<sup>2</sup>.

### (1) n-lateralization in /n/

Input	Output	Gloss	Related forms
/non + li/	[nolli]	'logic'	[non] 'discussion' /li/ ([i]) 'reason' [nonceŋ] 'dispute' [illi] 'some reason' [c <sup>h</sup> uri] 'reasoning'
/han + lyar/	[hallyar]	'limit'	[han] 'limit' /lyar/ ([yar]) 'quantity' [hangye] 'boundary' [toyrarŋhyŋ] 'weights and measures'
/c <sup>h</sup> ən + li/	[c <sup>h</sup> əlli]	'natural law'	[c <sup>h</sup> ən] 'sky'

This n-lateralization process is also attested when a lateral precedes a nasal /n/, as the examples in (2) illustrate.

<sup>2</sup> Components of each compound are included as related forms and their meanings are indicated. In Korean, a lateral is deleted in word-initial onset position as shown in the example 'reason', and it is realised as a flap intervocally as the example 'reasoning' illustrates. In the case of a geminate lateral, it can occur in word-medial onset position as shown in the example 'some reason'. Other examples, which will be helpful in figuring out the underlying form, are also included as related forms.

## (2) n-lateralization in /ln/

Input	Output	Gloss	Related forms
/səl + nal/	[səllal]	'New Year's Day'	[səl] 'New Year' [nal] 'day'
/t <sup>h</sup> il + ni/	[t <sup>h</sup> illi]	'denture'	[t <sup>h</sup> il] 'frame' /ni/ ([i]) 'teeth' [sarəŋni] 'wisdom teeth'
/pul + niŋ/	[pulliŋ]	'incapability'	[pul] 'not' [niŋ] 'capability' [pulmyən] 'insomnia' [niŋnyək] 'capability'

However, when a lateral is preceded by a noncoronal nasal /m/ or /ŋ/, the lateral is nasalized as the examples in (3) illustrate<sup>3</sup>.

## (3) l-nasalization after a non-coronal nasal

Input	Output	Gloss	Related forms
/sam + lyu/	[samnyu]	'third rate'	[sam] 'three' /lyu/ ([lyu]) 'rate, class' [iryu] 'second rate'
/tam + lyək/	[tamnyək]	'courage'	[tam] 'gall' /lyək/ ([yək]) 'power' [siryək] 'eyesight'
/yəŋ + li/	[yənŋi]	'profit'	[yəŋ] 'administration' /li/ ([i]) 'profit' [sori] 'a small profit'
/saŋ + lyu/	[saŋnyu]	'the upper stream'	[saŋ] 'upper' /lyu/ ([lyu]) 'stream' [haryu] 'the downstream'

As for these two different sonorant assimilation processes, we can raise the question why it is that the nasal assimilates to the lateral when the nasal is coronal, but when the nasal is velar or labial, it is the lateral that assimilates in manner to the nasal.

## 3. The Realization of n/l sequences in other languages

While l-nasalization in /ml/ and /ŋl/ sequences is a rather uncommon process, n-lateralization in n/l sequences is attested not only in Korean but in a wide range of different languages. N-lateralization before a lateral is observed in languages such as

<sup>3</sup> No assimilation process is found in the /lm/ sequence as in /pal + mok/ → [palmok] 'ankle'. I leave this for future study and will not discuss it in this paper.

Klamath, Ponapean, Toba Batak, Moroccan Arabic, and Leti. Tatar and Yakut show a different alternation pattern. Unlike other languages, l-nasalization occurs in /nI/.

(4) a. n-lateralization in /nI/

Klamath: /honlina/ → [hollina] 'flies along the bank' (Barker 1964, Rice & Avery 1991)

Ponapean: /nan-leŋ/ → [nalleŋ] 'heaven' (Rehg & Sohl 1981, Rive & Avery 1991)

Toba Batak: /lean lali/ → [leal lali] 'give a hen-harrier' (Hayes 1986)

Moroccan Arabic: /ban + li/ → [balli] 'it seemed to me' (Amakhmakh 1997)

Leti: /na + losir/ → [llosir] '3sg, to follow' (Hume et al., 1997)

b. l-nasalization in /nI/

Tatar: /khayvan + lÄr/ → [khayvannar] 'animals' (Poppe 1963)

Yakut: /oron + lAr/ → [oronnor] 'beds' (Krueger 1962)

Languages such as Leti, Terafene dialect of Flemish, and Rendille illustrate n-lateralization after a lateral. Moroccan Arabic shows a different alternation pattern. Unlike other languages, the underlying /ln/ sequence surfaces as [nn].

(5) a. n-lateralization in /ln/

Leti: /vulan/ → [vulla] 'moon' (Hume et al., 1997)

Terafene dialect of Flemish: /spe:l-n/ → [spe:ll] 'to play' (Levin 1988)

Rendille: /yeel-n-e/ → [yeelle] 'we carved' (Sim 1981)

Somali: /dil + -nay/ → [dillay] '(we) killed' (Zorc and Osman 1993)

Udi: /k'alnexa/ → [k'allexa] '(s)he calls' (Schulze 2001)

b. l-nasalization in /ln/

Moroccan Arabic: /dyaI + na/ → [dyanna] 'ours' (Amakhmakh 1997)

Related to n-lateralization and l-nasalization in n/I sequences and l-nasalization in the /mI/ and /ŋI/ sequences, we can raise two important questions. First, why do n-lateralization and l-nasalization occur in n/I sequences cross-linguistically while l-nasalization in the /mI/ and /ŋI/ sequences is not attested frequently in other languages? Second, why can both n-lateralization and l-nasalization occur in n/I sequences cross-linguistically?

#### 4. Proposal: Perceptual Account<sup>4</sup>

Questions related to n-lateralization and l-nasalization in *n/l* sequences and l-nasalization in */ml/* and */ŋl/* may be answered by recourse to speech perception. Kohler (1990) and Hura et al. (1992) view assimilation as perceptually tolerated articulatory simplification. According to them, assimilation tends not to occur when the members of a consonant class are relatively distinctive perceptually, such that their articulatory reduction would be particularly salient. Steriade (2001) also provides a perceptually motivated account for phonological change such as assimilation by claiming that a sequence of acoustically similar segments is more likely to be selected for assimilation. According to Steriade, speakers' behavior is guided by a model of the generic listeners' perceptual abilities and biases. This model of the generic listener, which is called the P-map, has the function of identifying regions of relative safety within which a speaker can deviate from established pronunciation norms while minimizing the risk of being noticed. Thus, as the result of modification, among possible output forms for a given input, the one that differs least from the unmodified input form is preferred<sup>5</sup>.

Following this, we hypothesize that [l] and [n] are difficult to distinguish in sequence since they are acoustically and auditorily similar, and this permits assimilation to occur. This hypothesis is supported by Borden & Harris (1984), and Johnson (1997). According to them, [l] and [n] are acoustically and auditorily similar in that both have formant structure and the same place of articulation. They are distinguished only by small differences in the frequencies of the formants and antiformants during the consonant closure.

Based on Kohler (1990), Hura et al. (1992), and Steriade (2001), we can further hypothesize that, as the result of assimilation, either a geminate lateral or a geminate nasal is obtained since both [ll] and [nn] are like */nl/* and */ln/*. In other words, both changing [l] to [n] and changing [n] to [l] are perceptually allowed changes in *n/l* sequences.

As for assimilation in the */ml/* and */ŋl/* sequences, we hypothesize that it is attested less commonly cross-linguistically compared with assimilation in *n/l* sequences since the noncoronal nasals and lateral are less similar acoustically and auditorily. Although the noncoronal nasals and lateral all have formant structure, they differ in terms of place of articulation. Thus, it is expected that assimilation is frequently observed when more similar */n/* and */l/* segments are adjacent, while assimilation is less frequently observed when less similar */m/* or */ŋ/* and */l/* are adjacent. When assimilation is attested in the */ml/* and */ŋl/* sequences, we hypothesize that a lateral is nasalized since [mn] and [ŋn] are more similar to */ml/* and */ŋl/*, respectively, than they are to [ll]. In other words, changing the

<sup>4</sup> Davis (1999) provides an account of sonorant assimilation in Korean based on a syllable contact constraint prohibiting rising sonority over a syllable boundary. His analysis is problematic, among other things, in that it cannot generalize to cases in which syllable contact is not relevant. For example, in *Leti*, tautosyllabic */nl/* surfaces as [ll], as in */na + losir/* → [llosir] '3sg, to follow' (Hume et al., 1997).

<sup>5</sup> A similar account is also proposed by Kohler (1990).

lateral to a nasal results in a less noticeable change than would be the case if the nasal changed to a lateral. A perception experiment was run to test this hypothesis.

Given that the perceptual abilities (i.e. the P-map) proposed by Steriade are claimed to be universal, it is predicted that listeners' perception patterns will be the same regardless of the native language of a listener and sound patterns found in that language. That is, it is predicted that listeners will perceive both a geminate lateral and a geminate nasal as like /n/ and /ɲ/, and both [mn] and [ɲn] as more like /m/ and /ŋ/, respectively, than a geminate lateral. To test this hypothesis, a perception experiment was run. The universality of the P-map can be tested by comparing the results of the perception experiment obtained from Korean listeners with the results obtained from listeners of other languages which illustrate different phonological patterns in /n/, /ɲ/, /m/, and /ŋ/.

## 5. The Realization of nasal/lateral sequences in Moroccan Arabic and Swedish

Moroccan Arabic and Swedish differ from Korean in terms of the phonological patterns involving /n/, /ɲ/, /m/, and /ŋ/ sequences. Thus, a comparison of the results of the perception experiments obtained from Korean, Moroccan Arabic, and Swedish listeners will provide a good test of the P-map hypothesis.

### 5.1 Moroccan Arabic<sup>6</sup>

Moroccan Arabic is similar to Korean in that a nasal /n/ is lateralized before a lateral.

#### (6) n-lateralization in /n/ (Amakhmakh 1997)

Input	Output	Gloss
/ban + li/	[balli]	'it seemed to me'
/mən + lhih/	[məɭlhih]	'from there'

However, Moroccan Arabic also shows a number of differences from Korean. First, while the /ɲ/ sequence is realized as [ɲ] in Korean, the sequence is realized as [nn] in Moroccan Arabic, as the following examples illustrate.

#### (7) l-nasalization in /ɲ/ (Amakhmakh 1997)

Input	Output	Gloss
/l + na/	[nna]	'to us'
/mal + na/	[manna]	'what's the matter with us'

Second, unlike Korean, the velar nasal /ŋ/ does not belong to the Moroccan Arabic sound inventory. Thus, while the sequence /ŋ/ surfaces as [ɲn] in Korean, no consonant sequence having the velar nasal as one of its components is attested in Moroccan Arabic.

<sup>6</sup> In Moroccan Arabic, n-lateralization and l-nasalization are morphologically conditioned. They occur with specific types of morphemes such as definite prefix /l-/ (Heath 1987; Keegan 1986).

Third, with respect to the sequence /ml/, in Moroccan Arabic it surfaces as [ml] without any change; in Korean, on the other hand, it is pronounced as [mn]. Thus, both [ml] and [mn] are possible surface forms in Moroccan Arabic, as the examples in (8) illustrate (Harrell 1962; Heath 1987).

(8) Input	Output	Gloss
/šrahom + lek/	[šrahomlek]	'he bought tem for you (sg.)'
/z̥tm + l + ha /	[z̥tmlha]	'he stepped on her (foot, etc.)'
/qeddem + na/	[qeddemna]	'we presented'
/sellem + na/	[sellemnna]	'we greeted'

## 5.2 Swedish

Swedish is different from Korean and Moroccan Arabic in that no alternation patterns are found when a lateral is adjacent to another sonorant, although a geminate lateral and nasal exist, as shown in the examples [alla] 'all' (Pyun 1987) and [hennes] 'her' (NTC Publishing Group, 1997). Thus, the sequences /nl/ and /ln/ surface as [nl] and [ln], respectively, without undergoing assimilation.

(9) Input	Output	Gloss
/vanlig/	[vanlig]	'usual'
/manlig/	[manlig]	'male'
/molnig/	[molnig]	'cloudy'
/falna/	[falna]	'die down'

In addition, no alternations are found when a lateral is preceded by a noncoronal nasal. Thus, the underlying sequences /ml/ and /ŋl/ surface without undergoing assimilation. The sequences [mn] and [ŋn] are also possible surface forms.

(10) Input	Output	Gloss
/hemlig/	[hemlig]	'secret'
/næ mna/	[næmna]	'mention'
/viŋla/	[viŋla]	'stagger'
/reŋna/	[reŋna]	'rain'

## 5.3 Summary

We can summarize the phonological patterns involving /nl/, /ln/, /ml/, /ŋl/ sequences found in Korean, Moroccan Arabic, Swedish as follows:



Table 1. A summary of the patterns

Underlying Sequence	Surface Realization		
	Korean	Moroccan Arabic	Swedish
/nI/	[II]	[II]	[nI]
/In/	[II]	[nn]	[In]
/mI/	[mn]	[mI]	[mI]
/ŋI/	[ŋn]		[ŋI]

## 5.4 Testing the P-Map Hypothesis

According to the P-map hypothesis (Steriade 2001), listeners' perceptual abilities are the same regardless of the native language of a listener and sound patterns found in that language. As shown above, Moroccan Arabic and Swedish show different phonological patterns in nasal/lateral sequences from Korean. If Korean, Moroccan Arabic, and Swedish listeners show the same perception patterns in the perception experiment, the P-map hypothesis will be supported. However, if it is hypothesized that the input and output of assimilation are perceptually confusable, it is expected that language-particular sound patterns influence listeners' perceptual abilities. Thus, according to this hypothesis, it is expected that Swedish listeners will perform the perception experiment better overall, compared with Korean and Moroccan Arabic listeners since all nasal/lateral sequences concerned exist as surface forms in Swedish. In addition, Korean listeners are expected to perform the perception experiment worse since /nI/, /In/, /mI/ and /ŋI/ do not surface in Korean. Since /In/ is realized as [II] in Korean, it is expected that Korean listeners perceive /In/ as more similar to [II] than to [nn]. In the cases of Moroccan Arabic listeners, it is expected that they will show different perception patterns from Korean listeners by perceiving /In/ as more similar to [nn] than to [II], considering that /In/ is realized as [nn] in Moroccan Arabic. Since /nI/ is realized as [II] in Moroccan Arabic as it is in Korean, it is expected that Moroccan Arabic and Korean listeners will perceive /nI/ as more similar to [II] than to [nn].

## 6. Methods

### 6.1 Stimuli

For the experiment, recordings of ten repetitions of the sequences [anla], [alna], [anna], [alla], [amla], [aŋla], [amna], and [aŋna] were made by a Hindi speaker in a sound-attenuated booth at the Ohio State University and digitized at 22050 Hz. For the recordings, a head-mounted microphone (SM10A SHURE ) and a TEAC V-427C tape recorder were used. Stimuli recordings were made by a Hindi speaker since every consonant sequence in the stimuli occurs in Hindi<sup>7</sup>.

The types of stimuli presented to listeners are as follows:

<sup>7</sup> The perception experiment was not run with Hindi listeners to avoid potential native language effects. For the same reason, stimuli recordings were made by a Hindi speaker rather than by a Swedish speaker, although every sequence used in this perception experiment occurs in Swedish.

(11)	[anla]/[anla]	[alna]/[alna]	[anna]/[anna]
	[anla]/[anna]	[alna]/[anna]	[alla]/[alla]
	[anla]/[alla]	[alna]/[alla]	
	[amla]/[amla]	[aŋla]/[aŋla]	
	[amla]/[amna]	[aŋla]/[aŋna]	
	[amla]/[alla]	[aŋla]/[alla]	

To make these paired stimuli, four repetitions were taken for permutation from ten repetitions digitized for each stimulus. For each pair with the same stimuli (i.e. [anla]/[anla], etc.), twelve pairs of stimuli were obtained after permutation, while sixteen pairs of stimuli were obtained in the case of a pair with different stimuli (i.e. [anla]/[anna], etc.). As illustrated in (11), there are 6 pairs consisting of the same stimuli and 8 pairs consisting of different stimuli. To have the same number of 'same' and 'different' stimuli, 8 pairs were taken from the twelve pairs obtained after permutation for each identical stimulus and 6 pairs were taken from the sixteen pairs for each different stimulus. By this procedure, 48 pairs were obtained for identical stimuli, and another 48 pairs for different stimuli, totalling 96 pairs in all. All types of stimuli were presented to listeners in the order illustrated in (11). That is, in the presentation of the stimulus pair [anla]/[anna], for example, [anla] was presented before [anna].

## 6.2 Listeners

The listeners were 20 native speakers of Seoul Korean (10 males, 10 females), 22 native speakers of Swedish (8 males, 14 females), and 7 native speakers of Moroccan Arabic (6 males, 1 female). The age range for the Korean listeners was 20 to 36 years, with all having lived in the U.S. between 1 and 15 years (average 4 years). Two Swedish female listeners were students at the Ohio State University, 25 and 31 years old, both of whom have lived in the U.S. for 5 years. Twenty Swedish speakers were students at Lund University in Sweden, ranging in age from 20 to 57 years. The age range for the Moroccan listeners was 24 to 37 years, with all having lived in the U.S. between 1 and 2 years.

## 6.3 Task

The task of the listeners was to determine whether members of a pair of stimuli they heard are the same or different. Error rate and reaction time were recorded to use as an indicator of ease of perception in the analysis. For the discrimination test, the MEL program was used. The inter-stimulus interval was 500 ms and the reaction time clock started at the onset of the second stimulus in each pair. For the reaction time, the program was set to measure the time between the onset of the second stimulus and the point that a listener pressed the response button. Listeners were instructed to press the SAME button if they thought the pair of stimuli they heard were the same or the DIFFERENT button if they thought the pair of stimuli they heard were different. They were instructed to respond as accurately and quickly as possible and to look at the screen during the experiment. To enable a quick response, listeners were asked to use one hand to press the

SAME button and the other hand to press the DIFFERENT button. The stimuli were played through the headphones in a sound-attenuated booth.

Listeners heard 96 pairs of stimuli twice: once at approximately the speech reception threshold (40dB) and once again at a comfortable listening level (70dB)<sup>8</sup>. Listeners worked through the experiment at the speech reception threshold before they heard the stimuli again at a comfortable listening level. The experiment at the speech reception threshold (that is, at 40dB) was done for the purpose of eliciting mistakes.

#### 6.4 Predictions

Based on the claims made by Kohler (1990), Hura et al. (1992), and Steriade (2001), several predictions can be made. First of all, since both n-lateralization and l-nasalization are attested in n/l sequences cross-linguistically, and l-nasalization rather than nasal-lateralization occurs in /ml/ and /nl/ in Korean, Korean listeners are predicted to perceive the members of the [anla]/[alla], [anla]/[anna], [alna]/[alla], [alna]/[anna], [amla]/[amna], and [aŋla]/[aŋna] as more similar to each other than the pairs [amla]/[alla] and [aŋla]/[alla]. Furthermore, it is predicted that it will take more time to discriminate the former pairs than the latter pairs under the assumption that a similar pair will be harder to discriminate. Finally, based on the proposed universality of the P-map, it is predicted that the results of the discrimination test will not show language effects. Thus, Swedish and Moroccan Arabic listeners will give the same responses as Korean listeners.

### 7. Results and Discussion

#### 7.1 Reaction Time

For the reaction time analysis, only the reaction time of the correct responses for different stimuli was considered. To avoid the influence of outliers on the results, each subject's median reaction time was calculated for each pair type. There were cases in which subjects gave no correct response, and thus no median reaction time can be given. In such cases, reaction time was filled in by an expected value obtained by the addition of a mean deviation for pair type, which is calculated by subtracting a pair type mean from the total mean, and a mean of the subject's median reaction time.

We analyzed the obtained data in a repeated-measures analysis of variance (ANOVA) having one between-listeners factor (**language**: Korean, Moroccan Arabic or Swedish), and two within listeners factors (**loudness**: 40dB or 70dB; **pair type**). The results of the analysis of variance are shown in Table 2.

<sup>8</sup> We used 40 dB as the speech reception threshold level based on Winters (2000).

Table 2. Repeated Measures of ANOVA of Reaction Time. (The effects marked with bold face and \* were significant at  $p < 0.01$ .)

Source of Variance	DF	F
Between listeners		
Language	2	.6
Within listeners		
<b>Loudness</b>	1	29.7*
<b>Pair type</b>	7	23.6*
Loudness * Language	2	3.1
Pair type * Language	14	1.6
<b>Loudness * Pair type</b>	7	2.7*
Loudness * Pair type * Language	14	1.3

The effect of loudness was reliable in this analysis. On average, the mean reaction times were 851.6 ms for 40 dB and 747.5 ms for 70 dB. Thus, listeners' reaction time was slower when the stimuli were played at the reception threshold level, that is, at 40 dB.

There was also a main effect of **pair type**.

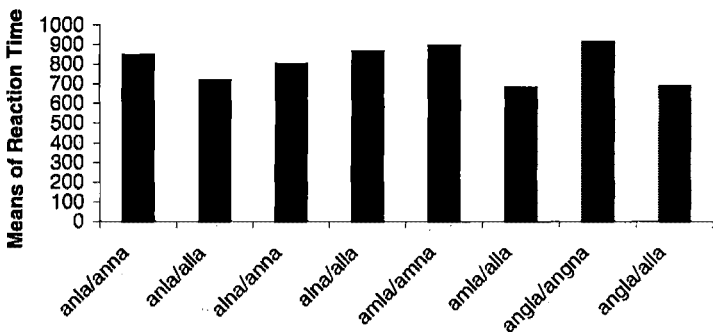


Figure 1. Pairtype

As can be seen in figure 1, the pair types [amla]/[amna] and [aqla]/[aqla] ('ŋ' is written as 'ng' in the figure) have longer reaction times than the pair types [amla]/[alla] and [aqla]/[alla], respectively. This is the expected result from our hypothesis: the input and output of an assimilation process is confusable perceptually and, thus, it will take more time to distinguish them. However, when it comes to the pair type [anla]/[alla], contrary to our hypothesis that there will be no perceptual difference between [anla]/[alla] and [anla]/[anna] since both n-lateralization and l-nasalization are attested in /n/ cross-linguistically, it has shorter reaction time than the pair type [anla]/[anna]. For the pair

types [alna]/[alla] and [alna]/[anna], contrary to our hypothesis, listeners showed longer reaction time in discriminating [alna]/[alla].

Another main effect in the analysis was the **loudness \* pair type** interaction.

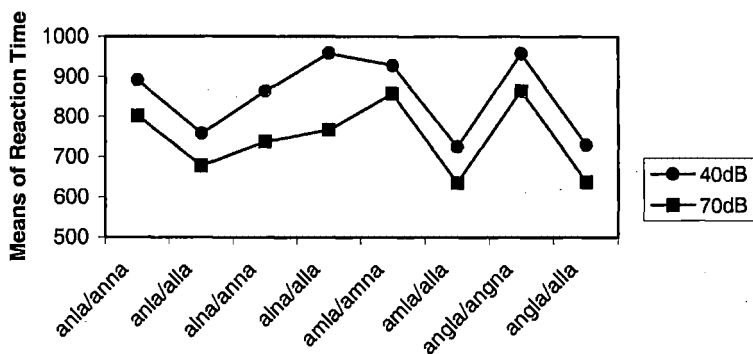


Figure 2. Loudness \* Pair type interaction

As we can see in figure 2, for every pair type the mean reaction time decreases as the loudness changes from 40 dB to 70dB. The overall pattern of each pair type is consistent at both 40 dB and 70 dB levels. Thus, the pair type [anla]/[alla], [amla]/[alla], and [angla]/[alla] have shorter reaction times at both loudness levels. In the cases of [alna]/[anna] and [alna]/[alla], they showed no significantly different reaction time at 70 dB. However, [alna]/[alla] showed a longer reaction time than [alna]/[anna] at 40 dB.

## 7.2 Discussion

The reaction time results are consistent with the hypothesis that l-nasalization in the /m/ and /ŋ/ sequences occurs since it is a perceptually less noticeable change than nasal-lateralization. As we expected, it took longer for listeners to discriminate between members of the pairs [amla]/[amna] and [angla]/[anna] than between members of the pairs [amla]/[alla] and [angla]/[alla]. The analysis also showed no language effect, thus, supporting Steriade's hypothesis that listeners' perceptual abilities are universal regardless of the native language of a listener and sound patterns found in that language.

However, the results contradict our hypothesis concerning n-lateralization and l-nasalization in /n/ sequences. According to our hypothesis, it was predicted that either /n/ is lateralized or /l/ is nasalized in /n/ sequences since both a geminate lateral and a geminate nasal are similar to /n/ and /l/. In the cases of the pair types [alna]/[alla] and [alna]/[anna], contrary to our hypothesis, listeners showed longer reaction time in discriminating [alna]/[alla] than [alna]/[anna]. For the pair types [anla]/[alla] and [anla]/[anna], although it was expected that it would take the same time to discriminate

between members of the pair [anla]/[alla] and between members of the pair [anla]/[anna], listeners were better at discriminating the pair [anla]/[alla] than the pair [anla]/[anna] as shown in figure 1.

There are several possible reasons for the results. One reason could be related to the significantly different duration of the stimulus [anna] and [alla], which were played as the second member of a pair. That is, if the duration of the stimulus [anna] used in the perception experiment was much longer than that of the stimulus [alla], it might trigger the longer reaction time for the pair type having [anna] as its second member. To test this, the duration of all repetitions of the stimuli [anna] and [alla] played in the perception experiment was measured. No significant duration difference was found between the two stimuli. Considering that for the reaction time the MEL program was set to measure the time from the beginning of the second stimulus to the point when a listener pressed the response button, different duration from the beginning of the stimulus [anna] or [alla] to the midpoint of a geminate might also be claimed to force the present result. If the stimulus [anna] had much longer duration between those two points, listeners' reaction time would be expected to be longer in the pair [anla]/[anna] (and also in the pair [alna]/[anna]). However, no such durational difference was found. Thus, we can exclude the possibility that the result was obtained due to the different durations of the stimuli [anna] and [alla].

Another possible reason for the result could be related to which consonant is different in each pair type; that is, whether the first or second consonant is different. If the first consonant of two stimuli is different as in the pair type [anla]/[alla], the reaction time is expected to be faster since listeners can decide whether two stimuli are different as soon as they listen to the first consonant of the second stimulus. However, when a pair type is composed of two stimuli differing in the second consonant as in [anla]/[anna], listeners would have to wait until they listened to the second consonant of the second stimulus, and thus it is expected that their reaction time will be longer. The longer reaction times of the pairs [amla]/[amna], [aŋla]/[aŋna] and [alna]/[anna] as compared to the pairs [amla]/[alla], [aŋla]/[alla] and [alna]/[alla] could have been influenced by this factor.

Thus, the reaction time analysis seems to be influenced by the position of the different consonant in a pair type. To see what the results are when the influence of this factor is excluded, an analysis considering listeners' sensitivity measure was done.

### 7.3 Sensitivity ( $d'$ ) measure

In performing the analysis of the results based on listeners' sensitivity measure, listeners' perceptual abilities were measured for each pair type using a sensitivity measure  $d'$ . This sensitivity measure takes into account a listener's bias to choose a particular response alternative by calibrating the 'hit rate' (the proportion of correctly recognized different stimuli) with the 'false alarm rate' (the mean proportion of incorrectly recognized same stimuli)<sup>9</sup>. The  $d'$  analysis might tell us more things about

<sup>9</sup> Hit = correct use of response "different"

False alarm = incorrect use of "different"

our discrimination test since it takes into account false alarm rate as well as hit rate while the reaction time analysis given above takes into account the reaction time of correct responses only.

The formula for  $d'$  is as follows:

$$(12) d' = z(H) - z(F),$$

where H is a hit rate, F is a false alarm rate, z means z-score.

Instead of getting  $d'$  values using the above formula, we used the tables in Kaplan, MacMillan & Creelman (1978) which show a  $d'$  value for given hit and false alarm rates (in the AX discrimination task).

The sensitivity data were analyzed using a univariate analysis of variance (ANOVA) having three between-listeners factors (**language**: Korean, Moroccan Arabic or Swedish; **loudness**: 40 dB or 70 dB; **pair type**: [anla]/[anna], [anla]/[alla], [alna]/[anna], [alna]/[alla], [amla]/[amna], [amla]/[alla], [aqla]/[aqla] and [aqla]/[alla]). The results of the analysis of variance are shown in Table 3.

Table 3. Univariate Analysis of Variance for Sensitivity ( $d'$ ). (The effects marked with boldface and \* were significant at  $p < 0.01$ )

Source of Variance	DF	F
<b>Language</b>	2	31.9*
<b>Loudness</b>	1	110.4*
<b>Pair type</b>	7	29.2*
<b>Language * Loudness</b>	2	10.1*
<b>Language * Pair type</b>	14	3.1*
<b>Loudness * Pair type</b>	7	2.8*
Language * Loudness * Pair type	14	3.9

One of the main effects in this analysis is the effect of **language**. As shown in figure 3, Moroccan Arabic and Swedish listeners showed higher sensitivity than Korean listeners.

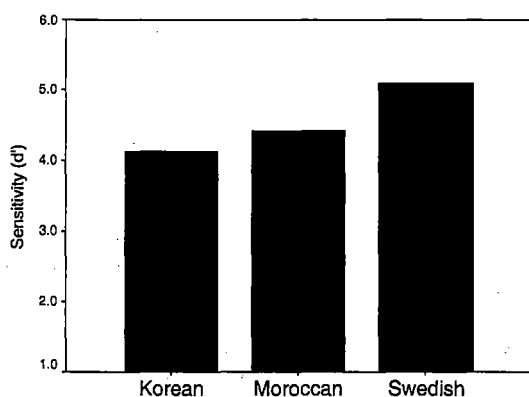


Figure 3. Language

Sensitivity ( $d'$ ) values were also significantly different for different **loudness** levels. The sensitivity ( $d'$ ) value was 3.9 at 40 dB and 5.1 at 70 dB. The effect of **pair type** was also reliable, as shown in Figure 4.

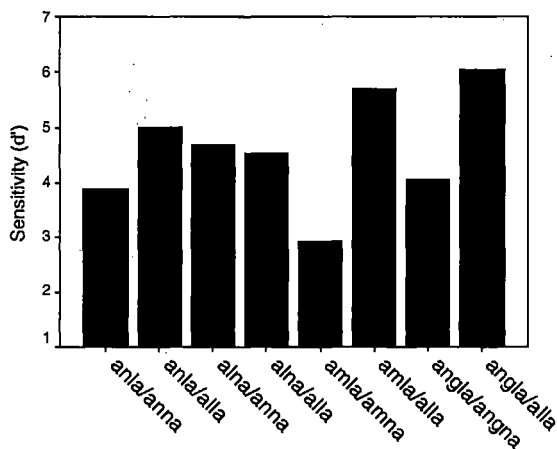


Figure 4. Pair type

The results from the sensitivity data are similar to those from the reaction time data. Listeners showed significantly lower sensitivity to the pairs [amla]/[amna] and [aŋla]/[aŋna] than to the pairs [amla]/[alla] and [aŋla]/[alla], respectively. Contrary to our hypothesis, the pair type [anla]/[anna] is higher in sensitivity than the pair type



[anla]/[alla], and, unlike the results from the reaction time data, but as we expected, the pair types [alna]/[anna] and [alna]/[alla] showed no significant difference in sensitivity.

The **language \* loudness** interaction showed that Swedish listeners were better at 40 dB and their sensitivity increased much more at 70 dB than it did for Korean and Moroccan Arabic listeners, as illustrated in figure 5.

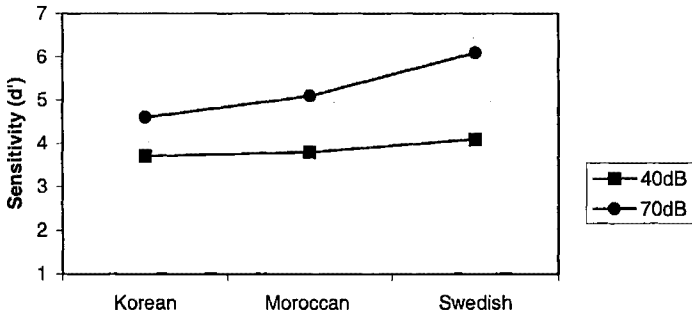


Figure 5. Language \* Loudness Interaction

The **language \* pair type** interaction is shown in figure 6.

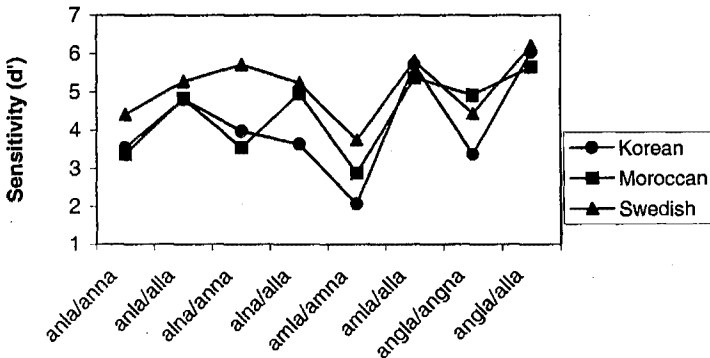


Figure 6. Language \* Pair type Interaction

Swedish listeners showed relatively higher sensitivity overall across the pair types. Korean and Swedish listeners had significantly lower sensitivity to the pairs [amla]/[anna] and [aŋla]/[aŋna] than to the pairs [amla]/[alla] and [aŋla]/[alla]. Listeners' sensitivity difference between [anla]/[anna] and [anla]/[alla] was not significantly

different except in the case of Swedish listeners who showed higher sensitivity to [anla]/[alla] than to [anla]/[anna]. In the case of [alna]/[anna] and [alna]/[alla], as we expected, there was no significant sensitivity difference for any group of listeners.

The **pair type \* loudness** interaction showed that listeners' sensitivity to the pair types [alna]/[alla], [amla]/[amna], and [aŋla]/[aŋna] increased more, compared with other pair types when they were heard at 70 dB. It is interesting that [alna]/[alla] has higher sensitivity than [alna]/[anna] at 40 dB while [alna]/[anna] has higher sensitivity than [alna]/[alla] at 70 dB while other pair types in comparison showed consistent patterns across the two loudness levels.

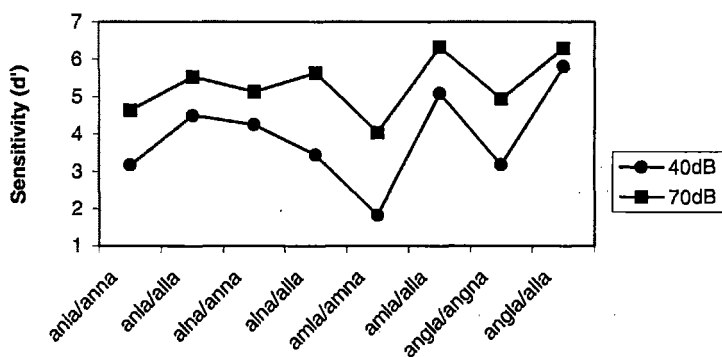


Figure 7. Pair type \* Loudness Interaction

#### 7.4 Discussion

The result that Swedish listeners' sensitivity to every pair type was high is not surprising considering the fact that every consonant sequence tested surfaces in the language. Also, as shown in the **language \* loudness** interaction, Swedish listeners were better at 40 dB than both Korean and Moroccan Arabic listeners, and Swedish listeners showed a greater increase in the value of  $d'$  when the stimuli were played at 70 dB. It seems that this result is also related to the familiarity factor.

The sensitivity data analysis showed that Korean and Swedish listeners' sensitivity to [amla]/[amna] and [aŋla]/[aŋna] was significantly lower than to [amla]/[alla] and [aŋla]/[alla], respectively. This then supports the hypothesis that l-nasalization in the /ml/ and /ŋl/ sequences is influenced by listeners' perceptual abilities since they perceive [amla] and [aŋla] as more similar to [amna] and [aŋna], respectively. It is especially interesting that Swedish listeners showed the same perception pattern as Korean listeners even though the consonant sequences [ml], [mn], [ŋl], and [ŋn] all occur in Swedish. On the other hand, Moroccan Arabic listeners showed no significant difference in sensitivity between [amla]/[amna] and [amla]/[alla], and between [aŋla]/[aŋna] and [aŋla]/[alla].

Thus, the hypothesis that listeners' perceptual abilities are the same regardless of the phonological patterns of their native languages is supported by the results from Swedish and Korean listeners while it is not supported by those from Moroccan Arabic listeners.

It seems that the phonological patterns of a listener's native language also influence speech perception when we consider the fact that Korean listeners' sensitivity was lower, compared with that of Moroccan Arabic and Swedish listeners. Among the three languages, Korean is the only language neutralizing every nasal/liquid sequence discussed here. Thus, under our hypothesis that the input and output of neutralization are confusable, Korean listeners' lower sensitivity might be influenced by such Korean phonological patterns. Also, the result that there is no significant difference between [aŋla]/[aŋna] and [aŋla]/[alla] in Moroccan Arabic listeners might be the influence of the phonology of Moroccan Arabic in which /ŋ/ is not a possible speech sound.

Korean and Moroccan Arabic listeners showed no significant difference in sensitivity between [anla]/[anna] and [anla]/[alla], as we expected, while Swedish listeners showed higher sensitivity to [anla]/[alla] than to [anla]/[anna]. These results support our hypothesis in part that [anla]/[alla] is as confusable as [anla]/[anna] and thus both n-lateralization and l-nasalization are attested in different languages. One reason for the results from Korean and Moroccan Arabic listeners may relate to the vowel nasalization cue. In [anla]/[alla], the first vowels of the two stimuli are different phonetically due to the presence or absence of vowel nasalization, respectively. That is, in [anla], the first vowel is nasalized before a nasal consonant while there is no such nasalization in the first vowel of the stimulus [alla]. Thus, if only language universal cues are involved in the discrimination of [anla]/[anna] and [anla]/[alla], it is expected that the pair type [anla]/[alla] will be easier to be distinguished than the pair type [anla]/[anna], in which the first vowels of both stimuli are nasalized.

Vowel nasalization may also provide insight as to why, in figure 7, listeners' sensitivity to [anla]/[anna], [alna]/[alla], [amla]/[amna], and [aŋla]/[aŋna] is lower than to other pair types at 40 dB. In each of these pair types, the first vowels have the same status regarding the nasalization cue; they are either both nasalized or both nonnasalized. Thus, considering the vowel nasalization, we can say that these pair types are more confusable. Under the assumption that more confusable stimuli will be even harder to discriminate at the reception threshold level (40 dB), this result is expected and it suggests that vowel nasalization played an important role when discriminating between two stimuli in this test.

If the vowel nasalization factor is considered in the case of the pair type [alna]/[anna] and [alna]/[alla], it is expected that [alna]/[anna] will show a higher *d'* value than [alna]/[alla]. However, as mentioned before, the listeners showed no difference in the sensitivity to either pair types. Also, Swedish listeners showed higher sensitivity to [anla]/[alla] than to [anla]/[anna], while Korean and Moroccan Arabic listeners showed no significant sensitivity difference between those two stimuli. These results suggest that some other language-universal or language-particular factors might also influence speech perception. Since, in this analysis, we are unable to determine which phonetic or

language-specific factors influenced the value of *d'* and how much their influence is, we performed a linear regression analysis separately for each language.

## 8. Linear Regression

### 8.1 Hypothesis

We hypothesize that the presence or absence of a vowel-nasalization cue, a place contrast, and a geminate consonant in the stimuli, as well as different levels of loudness (that is, 40 dB or 70 dB) will be language-universal phonetic factors influencing listeners' perceptual abilities. If there is a vowel-nasalization contrast in a pair type as in [alna]/[anna], it is expected that listeners' sensitivity will increase. Also, if two stimuli have a place contrast, as in [amla]/[alla] or [aŋla]/[alla], it is predicted that it will be easier for listeners to discriminate between the members of the pair. It is also predicted that the presence of a geminate in a pair type such as [alna]/[anna] will increase listeners' sensitivity to that pair type due to the longer duration of a geminate consonant. Finally, the prediction is that stimuli played at 70 dB will increase listeners' sensitivity.

Table 4 shows how each pair type was coded for the linear regression analysis based on the proposed language-universal factors.

Table 4.

Pair Type	Place Contrast	Vowel Nasalization	Geminate	Loudness
[alna]/[anna]	No (0)	No (0)	Yes (1)	40 dB (0)
[alna]/[anna]	No (0)	Yes (1)	Yes (1)	70 dB (1)
[amla]/[amna]	No (0)	No (0)	No (0)	
[aŋla]/[aŋna]	No (0)	No (0)	No (0)	
[alna]/[alla]	No (0)	Yes (1)	Yes (1)	
[alna]/[alla]	No (0)	No (0)	Yes (1)	
[amla]/[alla]	Yes (1)	Yes (1)	Yes (1)	
[aŋla]/[alla]	Yes (1)	Yes (1)	Yes (1)	

As for place contrast and vowel nasalization, if a pair type has a cue, the value '1' was assigned, if the cue is absent, the value '0' was assigned. If a pair type contains a geminate, the value '1' was assigned and if not, the value '0' was assigned. Finally, for loudness, the value '0' was assigned to a 40 dB level and the value '1' to a 70 dB level.

Since language-specific factors might also influence listeners' perception, we considered the issue of neutralization: whether or not consonant sequences in two stimuli contrast with each other. Our hypothesis is that listeners will have a hard time discriminating between two stimuli if one stimulus is neutralized to the other in their native language. That is, Korean listeners' sensitivity to [alna]/[alla] is expected to be lower than to [alna]/[anna] since /alna/ is neutralized to [alla] in Korean. However, it is

expected that Moroccan Arabic listeners will show less sensitivity to [alna]/[anna] since /alna/ is neutralized to [anna] in Moroccan Arabic.

Different patterns of contrast in consonant clusters in each language may also influence speech perception. When consonant sequences in two stimuli contrast in one language, listeners of that language are expected to show higher sensitivity to the pair type consisting of those two stimuli. For example, the consonant sequence /ŋl/ and /ll/ do not contrast in Korean and Moroccan Arabic since /ŋl/ surfaces as [ɲn] in Korean and /ɾ/ does not belong to the Moroccan Arabic sound inventory. However, they do contrast in Swedish since both [ɲl] and [ll] surface. Thus, it is expected that Swedish listeners will show higher sensitivity to the pair type [aŋla]/[alla].

Table 5 shows how each pair type in Korean, Moroccan Arabic and Swedish was coded according to the language-specific factors: contrast and neutralization.

Table 5.

Pair Type	Contrast			Neutralization		
	Korean	Moroccan	Swedish	Korean	Moroccan	Swedish
[anla]/[anna]	No (0)	No (0)	Yes (1)	No (1)	No (1)	No (1)
[alna]/[anna]	No (0)	No (0)	Yes (1)	No (1)	Yes (0)	No (1)
[amla]/[amna]	No (0)	Yes (1)	Yes (1)	Yes (0)	No (1)	No (1)
[aŋla]/[aɲna]	No (0)	No (0)	Yes (1)	Yes (0)	No (1)	No (1)
[anla]/[alla]	No (0)	No (0)	Yes (1)	Yes (0)	Yes (0)	No (1)
[alna]/[alla]	No (0)	No (0)	Yes (1)	Yes (0)	No (1)	No (1)
[amla]/[alla]	No (0)	Yes (1)	Yes (1)	No (1)	No (1)	No (1)
[aŋla]/[alla]	No (0)	No (0)	Yes (1)	No (1)	No (1)	No (1)

If a pair type has two consonant sequences which contrast in a language, the value '1' was assigned, and if not, the value '0' was assigned. If a pair type consists of the input and output of manner neutralization in a language, the value '0' was assigned, otherwise the value '1' was assigned.

## 8.2 Results

The results of the linear regression analysis are shown in Table 6.

Table 6. Linear Regression of Sensitivity (d')

	Korean	Moroccan	Swedish
<b>R Square</b>	<b>.35</b>	<b>.20</b>	<b>.41</b>
<b>Constant</b>	<b>2.28</b>	<b>3.6</b>	<b>3.1</b>
place contrast	1.48	1.77	.51
geminate	.86		.73
loudness	.87	1.24	1.96
vowel nasalization	.81		.67
contrast		-1.02	
neutralization			

The value of R square measures the proportion of d' variability that can be predicted by the given model. That is, in the case of Korean, the model including place contrast, geminate, loudness, and vowel nasalization factors can predict 35% of the observed variation of d'. The remaining variation is due to other factors such as individual differences between listeners.

Since no paired stimulus used in the perception experiment shows any consonant sequence contrast in Korean, the contrast cue was deleted from the analysis. Thus, in Korean, place contrast, geminate, loudness and vowel nasalization are the cues influencing listeners' sensitivity. As we hypothesized, when such cues are present in a stimulus, listeners' sensitivity to that stimulus increased. Korean listeners' sensitivity was influenced most by the place contrast cue while the influence of loudness was relatively low in Korean listeners, as compared with Moroccan Arabic and Swedish listeners.

In Moroccan, the influence of the place contrast was the greatest. It is interesting that listeners' sensitivity to the stimuli decreased when the contrast cue was present.

The neutralization and contrast cues were deleted from the analysis of Swedish listeners' sensitivity data since the two members in every pair type contrast in Swedish. As in the results from Korean listeners, the presence of the cues place contrast, geminate, loudness, and vowel nasalization increased listeners' sensitivity. However, Swedish listeners were influenced most by the loudness cues.

### 8.3 Discussion

Korean and Swedish listeners' sensitivity to a stimulus was influenced by the language-universal phonetic cues: place contrast, geminate, and vowel nasalization. The presence or absence of phonetic cues influencing Korean and Swedish listeners' discrimination of each stimulus can be summarized as follows.

Table 7.

[amla]/[amna]	[amla]/[alla]	[aŋla]/[aŋna]	[aŋla]/[alla]
	place contrast geminate vowel nasalization		place contrast geminate vowel nasalization
[anla]/[anna]	[anla]/[alla]	[alna]/[anna]	[alna]/[alla]
geminate	geminate vowel nasalization	vowel nasalization geminate	geminate

The above table shows in detail which language-universal or language-particular cues influenced Korean and Swedish listeners' sensitivity ( $d'$ ) value. Listeners' significantly higher sensitivity to [amla]/[alla] and [aŋla]/[alla] than to [amla]/[amna] and [aŋla]/[aŋna], respectively, is caused by the phonetic cues such as place contrast, geminate, and vowel nasalization, which are all present in [amla]/[alla] and [aŋla]/[alla], and all absent in [amla]/[amna] and [aŋla]/[aŋna].

The results of the linear regression analyses also give insight into why Swedish listeners perceived the stimulus [anla]/[alla] more easily than the stimulus [anla]/[anna]. The former has an extra phonetic cue, vowel nasalization, which helps discriminate between [anla] and [alla]. However, it is still not clear why Korean listeners showed no significant sensitivity difference between [anla]/[anna] and [anla]/[alla]. In the cases of the stimuli [alna]/[anna] and [alna]/[alla], [alna]/[anna] has an extra phonetic cue, vowel nasalization. But Korean and Swedish listeners' sensitivity difference between [alna]/[anna] and [alna]/[alla] was not significant and it is not clear which factors triggered this result.

Moroccan Arabic listeners' sensitivity to a stimulus was influenced by the language-universal cues: place contrast and loudness and the language-specific cue, contrast. The presence or absence of phonetic cues influencing Moroccan Arabic listeners' discrimination of each stimulus is summarized in Table 8.

Table 8.

[amla]/[amna]	[amla]/[alla]	[aŋla]/[aŋna]	[aŋla]/[alla]
contrast	place contrast contrast		place contrast
[anla]/[anna]	[anla]/[alla]	[alna]/[anna]	[alna]/[alla]

By considering both the results of the linear regression analysis for Moroccan Arabic listeners given in Table 6 and phonetic cues influencing the discrimination of each stimulus given in Table 8, we can account for Moroccan Arabic listeners' perception patterns to some extent. In the case of the pairs [anla]/[anna], [anla]/[alla], [alna]/[anna] and [alna]/[alla], they do not include any phonetic or language specific cue influencing listeners' sensitivity. Thus, it is expected that listeners will show no difference in sensitivity between the pairs being compared. In the case of the pairs [amla]/[alla] and [aŋla]/[alla], they contain the place contrast cue which enhances listeners' sensitivity

while the pairs [amla]/[amna] and [aŋla]/[aŋna] do not contain it. Thus, it is expected that listeners' sensitivity to [amla]/[alla] and [aŋla]/[alla] will be higher. However, Moroccan Arabic listeners displayed no significant difference between the two stimuli being compared and it is not clear which other factors triggered this result.

## 9. General Discussion

As an indicator of ease or difficulty of perception, we used reaction time and sensitivity ( $d'$ ) data. As mentioned above, it seems that listeners' reaction time was influenced by some non-linguistic factors such as the position in which different consonants are located in a paired stimulus. Thus, it seems that it will be better to discuss sonorant assimilation patterns based on the results from the sensitivity data, although the results from the two analyses are almost identical.

The sensitivity ( $d'$ ) data results suggested that l-nasalization in /ml/ and /ŋl/ is influenced by speech perception. As expected, [amla]/[amna] was more confusable than [amla]/[alla], and [aŋla]/[aŋna] was more confusable than [aŋla]/[alla] in Korean. Since changing /l/ to [n] is a less noticeable change in /ml/ and /ŋl/ perceptually, it is expected that the lateral /l/ is nasalized when sonorant assimilation occurs in those sequences, as in Korean.

Korean listeners showed no significant sensitivity difference between [anla]/[anna] and [anla]/[alla], and between [alna]/[anna] and [alna]/[alla]. This result supports our hypothesis that the degree of noticeability or salience between the two stimuli being compared is the same. That is, both changing /l/ to [n] and /n/ to [l] in n/l sequences are perceptually allowed changes, and thus both changes are attested in languages. If this is the case, we can then raise the question concerning which non-perceptual factors force l-nasalization, n-lateralization, or both in one language. As one possible factor, we can consider speakers' tendency to reduce speaking effort. In the production of [anna], extra articulatory effort to lower the velum is required, while no such effort is required in producing [alla]. Thus, we can say that speakers may prefer changing perceptually bad /nl/ and /ln/ sequences to a geminate lateral, as in Korean. Given this, why do /ml/ and /ŋl/ sequences surface as [mn] and [ŋn], respectively, if the production of a geminate lateral requires less speaking effort? In this case, it is because a speaker can deviate from established pronunciation norms while minimizing the risk of being noticed. As our perception experiment results showed, changing /ml/ and /ŋl/ to a geminate lateral is more noticeable than changing /l/ to [n]. Thus, /ml/ and /ŋl/ surface as [mn] and [ŋn], respectively, in this case.

In Moroccan Arabic, a nasal /n/ is lateralized in the /nl/ sequence while a lateral /l/ is nasalized in the /ln/ sequence. According to our experiment results from Moroccan Arabic listeners, both are perceptually allowed changes since no significant sensitivity difference was found between changing /l/ to [n] and changing /n/ to [l] in n/l sequences. Given speakers' tendency to reduce speaking effort discussed above, however, it is expected that both /nl/ and /ln/ be realized as [ll]. We can then raise the question why n-



lateralization is attested in /nI/ and I-nasalization in /In/. As one possible answer to this, the force preserving a prevocalic consonant which has been claimed to be perceptually stronger than a coda consonant by many researchers, can be considered. Thus, /VnIV/ changes to [VIIV] and /VInV/ to [VnnV] in Moroccan Arabic<sup>10</sup>.

## 10. Conclusion

This paper investigated the influence of speech perception as a source of explaining sonorant assimilation in Korean. The results suggest that I-nasalization in the changes from /mI/ and /ŋI/ to [mn] and [ɲn], respectively, is driven by perceptual considerations. However, the perception experiment results and assimilation patterns in n/I sequences suggest that listeners' perceptual abilities are not the only factors shaping the phonological patterns of languages. Rather, articulation as well as perception is relevant. That is, not only the change made by assimilation should be perceptually less noticeable, but it should also be articulatorily easy.

Our perception experiment results also showed that the universality of Steriade's P-map is supported in part. In general, universal speech perception patterns are attested between two groups of listeners whose native languages are different. However, at the same time, languages may deviate from a universal perception pattern. In this study, Swedish listeners showed different perception patterns from Korean and Moroccan Arabic listeners by having higher sensitivity to [anla]/[alla] than to [anla]/[anna] while Korean and Moroccan Arabic listeners had no sensitivity difference between those two stimuli. Moroccan Arabic listeners displayed different perception patterns from Korean and Swedish listeners by showing no sensitivity difference between [amla]/[amna] and [amla]/[alla], and [aŋla]/[aɲna] and [aŋla]/[alla] while Korean and Swedish listeners showed higher sensitivity to [amla]/[alla] and [aŋla]/[alla].

Finally, our perception experiment results showed that speech perception is influenced by phonological patterns of a listener's native language. We speculate that Korean listeners had lower sensitivity compared with other listeners due to the phonological patterns in Korean where /nI/, /In/, /mI/ and /ŋI/ never surface as the result of neutralization.

<sup>10</sup> In Tatar and Yakut, the underlying /nI/ is realized as [nn], as mentioned in section 3. According to our perception experiment results, this is a perceptually allowed change. However, it is not clear which factor forces the prevocalic /I/ to be changed to [n] resulting in a geminate nasal which requires more articulatory effort than a geminate lateral. I leave this for future study.

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